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ABSTRACT

This paper discusses, in general terms, when the use of computer based instructional simulation (CBIS) is appropriate, and offers suggestions on constructing an effective instructional simulation, placing a particular emphasis upon documentation. Two examples of simulation are given with descriptions of useful methods for evaluating CBIS. (Author/CHV)

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THE WHENS AND HOWS OF COMPUTER BASED INSTRUCTIONAL SIMULATION

By
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THE WHENS AND HOWS OF COMPUTER BASED INSTRUCTIONAL SIMULATION

ABSTRACT

The paper discusses, in general terms, when the use of computer based instructional simulation (CBIS) is appropriate. It offers suggestions on constructing a good instructional simulation. Documentation is particularly stressed. Two examples of simulation are given.

KEYWORDS

Computer-Based Instructional Simulation, Instructional Design, Evaluation, and Documentation.

INTRODUCTION

Computer-Assisted Instruction (CAI) and particularly that subgroup of CAI called Computer-Based Instructional Simulation (CBIS) can be effective tools for teaching certain types of concepts. To date, however, most studies comparing CBIS with other teaching methods have measured aspects of the student's performance for which the traditional teaching forms would be expected to perform at their best, e.g. factual recall and concept definition. This evaluation problem is due in large degree to the fact that some learning outcomes are inherently more amenable to assessment; this is especially true with evaluation instruments which employ traditional multiple choice or short answer formats. It has been recognized CBIS does have unique capabilities for teaching; these capabilities have been referred to as desirable but unassessed benefits (Edwards).

This paper will specify these benefits and test for them in a CBIS package. In order to assess the potential benefits of CBIS, three questions will be addressed. First, what makes a good CBIS? Second, for what types of learning is CBIS best suited? Third, how should the effectiveness of CBIS by evaluated? In this paper testing methods will be suggested along with a discussion of their use in two CBIS packages.

GENERAL PROPERTIES OF CAI

Many properties of CAI have been touted as desirable features of an instructional system. These features include student motivation, feedback, error detection and correction, reproducibility of teaching, the computer's imperturbability, the freedom of students to work at their own pace, the individualization of instruction, the ability to improve the way the material is taught, and the record-keeping ability of the computer (Inbar and Stoll). While we feel that all of these attributes are important and feasible in a fully developed CAI package, CAI packages to date have not made proper use of them because the program authors lack experience and guidelines; this lack has led to much justified criticism of CAI.

One potential benefit of CAI was not mentioned in the list above: providing enhanced "intuitive grasp" of concepts and interrelationships. Bork (1977) notes that :

> A complaint often registered at doctoral examinations is that some graduate students can carry out the mathematical manipulations, even for very advanced problems, but have little physical intuition as to what is happening.

Bork continues by suggesting that CBIS or "controllable worlds" will give the student the experience and insight necessary to understand a problem intuitively.

WHEN: EFFECTIVE INSTRUCTIONAL DESIGN FOR CBIS

As has been suggested, CBIS is exceptionally effective for teaching certain types of concepts and quite unsuitable for teaching others. CBIS is particularly well-suited for teaching process concepts, the interrelationships between process concepts, and multifaceted/multi-step problem solving.

Process Concepts

Process concepts are conceptualizations of processes. Normally these processes take place through time and across space. Process concepts occur at the highest level of cognitive learning and the student needs the maximum amount of assistance in learning these concepts. This type of concept is difficult to teach using traditional methods because processes cannot be shown in action. Even when processes can be shown in action, as in a movie, the student has no control over the independent variables nor the environment. In physics, chemistry, and biology the laboratory has been used to supplement the material taught in the classroom, so that the student gains a greater understanding of the process by experience — the experiment. Pedagogic experiments are performed with the student "controlling" the variables so that he can see the cause-effect relationship and the processes in action. Unfortunately many processes take too long, are too subtle, too cosmic, or too microscopic in nature to be brought into a laboratory. But, as Bork noted, the intuitive understanding of process concepts can be extremely important. In teaching process concepts, the social sciences face the problem of the student's lack of intuition about such concepts (which the teacher expects him to know on an intuitive level as well as a mathematical level) because here the objects of interest are the economy, political and social systems, and the people of a region. These objects of study involve processes which cannot be shown in action; nor can they be experimented with — only politicians have such opportunities. In teaching these process concepts and many others, CBIS can fill the laboratory-learning gap.

CBIS has many of the positive instructional attributes of well-planned lab work, plus additional advantages over laboratory experiments. The advantages of CBIS include: the enhancement of certain key features of the experimental experience so that these features are perceived the first time through; the ability to speed up or slow down time; and the ability to enlarge or contract the space that the experiment requires so that the patterns and processes can be easily perceived. Thus, CBIS can be used to great advantage for teaching process concepts because it can focus on and enhance the image of a process as it is simulated. Depending on the type of terminal — teletype or teletype emulator CRT, semi-graphic CRT, or color graphics CRT — a CBIS can closely duplicate the laboratory situation for the student.

Interrelationships Between Concepts

Relationships between concepts are difficult to teach using traditional methods because those methods are static and cause-effect relationships are difficult to demonstrate.

While demonstrating the general form of a relationship is possible using audio-visual aids, the student will still have difficulty understanding the magnitude of the relationship. This is the second type of learning for which CBIS is ideally suited. CBIS allows the student to manipulate the independent variables to predict the dependent variables. When a student can create the causes and see their effects on the process, the magnitude of the relationship is much more likely to become apparent. If a student understands the magnitude of a relationship, he/she should then be able 1) to predict the effect that given values of an independent variable will have on the dependent variable and 2) to choose values of independent variables that will produce a given effect on the dependent variables. In this manner a student can demonstrate his/her understanding of the relationship between the variables involved in the process.

Multifaceted/Multi-step Problem Solving

Multifaceted/multi-step problem solving is the third type of learning that is properly taught using CBIS. Problem solving techniques, particularly when the problems have multiple variables or use multiple step procedures, are among the most difficult types of procedures to teach because they involve both cognitive and behavioral learning processes. CBIS can provide a controlled environment in which the student can learn some or all of the problem solving techniques that he will need to know before he is faced with the actual problem.

Learning to solve multifaceted/multi-step problems usually requires repeated practice; the student learns by doing. Such problems include learning to play a sport, driving a car, flying an airplane, handling complex machinery, diagnosing and repairing communications equipment, or designing and constructing lighting for plays. CBIS has already been used to teach emergency procedures while flying an airplane. It would obviously be bad for business to lose several Boeing 747s while pilots were practicing in them. Less dramatic examples include teaching diagnostic techniques to prepare medical students for their practice on patients. Law students can practice preparing and presenting briefs and cases. Business students in accounting, management, and marketing use CBIS to practice their decision making. In all cases multiple variables need to be accounted for, and there are multiple problems to be solved.

Since the early 1960s, many business schools have used noninteractive simulations, like the "Executive Game," to teach their MBA students management techniques used in a competitive business situation. The students compete against one another with profit being the main criterion for deciding success or failure. Since many of these games have since been written or rewritten in interactive simulations, e.g. Market, they must be valuable for teaching management procedures. The management procedures being taught are of the multifaceted/multi-step variety. In the management games, the student controls some variables. Student controlled independent variables include the price of the good, the fixed and variable costs associated with producing the good, research and development costs, marketing costs, plus a sundry of other controllable costs depending on the simulation. Independent variables that are not student-controlled include the prices and advertising investments of other firms (students) and "random" events like new labor costs and fires in warehouses. This forces the student to make decisions in a realistic manner or face business failure and a low grade in the course. Likewise, it gives him a chance to see how good his problem solving ability is when compared to his peers, so that he can decide whether he should attempt a career in management, and also where his strengths and weaknesses lie.

Simulations designed to help the student learn diagnostic, problem-solving, or decision-making techniques must have output that is sufficiently realistic that the student feels that he is actually making the decisions or solving the problem while he is running the simulation — otherwise the simulation is at least a partial failure. So, for simulation designed for this purpose in particular, the mode of output is extremely important.

HOW: PROPERTIES OF CBIS — ITS USE AND EVALUATION

The Use of Special Properties of CBIS

When you decide to write a CBIS for teaching there are several properties of CBIS that you should be aware of. First, CBIS should be used only when it is the best instructional method for the material. Second, good CBIS should use the maximum capabilities of the terminals and computer system. Third, as CBIS becomes complex it should have more documentation. Fourth, a good CBIS package should contain sufficient ancillary material and programming to make learning easy for the student.

Use CBIS Only When Needed

The best known and by far the most realistic and sophisticated CBISs, the simulations of every phase of the Apollo moon missions, were constructed for teaching process concepts, the relationships between concepts, and multifaceted problem solving abilities. Astronauts and ground personnel were given every conceivable type of problem to solve that might be encountered during a mission. They repeatedly practiced solving these problems, learning the relationships of the system hardware and software so well that when a potential catastrophe occurred in Apollo 13, the CBIS system produced the solution to the problem. So first, good CBIS should concetrate on teaching processes or process concepts, their relationships, and multifaceted problem solving. Other less time-consuming teaching methods should be used when less complex concepts or techniques are taught.

Maximize Capabilities

Second, a good CBIS should make the best possible use of the computer system's and terminal's capabilities. There are two philosophies regarding the presentation of simulation: 1) use standard techniques, i.e. make the material teletype-33 compatible, or 2) fully use the inherent capabilities of the computer complex on which you are working. The first philosophy is justified by the fact that "ALL terminals" can use the program, making the simulation transportable or easily transferable from terminal to terminal. This is of great importance on campuses where there are 5 or 6 different types of terminals, and not one of sufficient number to serve a large class. The generally unrealized expense of this type of programming is complete underdevelopment of the visual illustrations and graphic demonstrations so important to good teaching. The importance of visual illustrations is well documented (Lackmann) and well known to all teachers. For a long time the blackboard (and recently the overhead projector) was the important teaching aid in the lecture classroom. So, too, the graphic capabilities of the computer complex should be of the highest value to CBIS when used appropriately. Unfortunately, the program complexity increases with the complexity of the visual effects, but this should not serve as an excuse for not using the capability of the computer system, any more than lack of ability to draw is a good excuse for not using the blackboard. Nor is the excuse of incompatibility of terminals sufficient because there are simple ways to program so that terminals with similar capabilities, but different instruction sets, can use the CBIS material [1]

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[1] Teletype-33 programming also increases any deficiencies in the desired features of CAI mentioned above.

Documentation

If there is one problem that all CAI packages suffer from, it is the lack of adequate documentation. This is particularly true as the CAI packages increase in complexity, like CBIS. It is imperative that the concepts and techniques and their underlying assumptions can be either in the form of computer tutorial material or manuals. A few notes from the author to himself, or a "user's" manual that describes only how to start the program, are not sufficient documentation.

There are three types of manuals and two modes of presenting documentation. First, there is the instructor's manual. It should include the objectives the package is designed to teach, structure for presenting the concepts, background information on the concepts, and suggestions for integrating the material into the course. The second manual is the user or student manual. It should include any information that the student needs to know before running the package, instructions on how to get the package into operation, instructions on how to get out of trouble, and supplementary information on the origin of the concepts of the package. The third manual is the technical manual for the technical personnel in charge of bringing the package on-line on the computer. It should explain the purpose and structure of the various programs in the package and contain lists or legends of the main variables, arrays, and pointers or indicators, so that a programmer can make the site-specific modifications required when a complex package is moved to a different computer complex. A detailed description of the organization of these manuals is beyond the scope of this paper. But an excellent documentation of this organization is already available in CONDUIT'S *Author's Guide*.

The two modes of presenting material contained in the manuals are printed and interactive. Normally manuals on how to use something, be it a chainsaw or computer program, come in booklet form as this is the only economic way to transmit the information. However, the author of the computer program has another tool readily available, the computer, which allows him to present appropriate material and instructions to the user interactively. But what is appropriate material? We believe that appropriate material includes instructions or help units in tutorial format that let the user know what is coming next in the simulation; which explains details of alternatives when the user is asked to make a choice, and that explains the details and bases of concepts used by the simulation. Inappropriate material to present via computer includes the rules of the simulation, supplementary references or long, detailed, explanations of the concepts or of the workings of the simulation. While the distinction between appropriate and inappropriate material may be a bit fuzzy, the best rule of thumb would be: if there are more than 24 lines that are 80 characters long (one full CRT screen) of explanatory material without a user response, then the material belongs in a manual. Use interaction, don't write a textbook. And if you must make a decision between writing more documentation or not, always write more. (It can always be ignored, but may be important to someone for reasons not readily apparent to you.)

Ancillary Material

The fourth property of good CBIS is that it must have sufficient ancillary material, both tutorials and manuals, to allow for effective and efficient use of the simulation. The one distinguishing characteristic of institutional simulations is that they are designed to teach complex processes and concepts. They can't do their job properly unless the user understands the simulation and its bases. There are several simulations that would be excellent instructional simulations, but the authors failed to realize that the complete simulation would overwhelm the beginning user with too many multiple options.

Good CBIS material provides for these neophytes in one of two ways. First, the simulation can be constructed in several versions, simple to complex, so that the beginner can get a feel for using the simulation before graduating to the next more complex version. One simulation can be devised that accomplishes this task of creating multiple versions. The program asks at what level the user wishes to work, then defaults to standard options for the beginner if no advanced option is requested. If the user's decision time is an important variable in the simulation, this can be decreased as the level of expertise increases. Second, the CBIS program novice can construct a set of tutorial lessons to teach concepts and options to the student. These lessons can include traditional CAI tutorials (programmed instruction, games, mini-simulation), sections of the actual simulation, or the complete use of the simulation. In practice these teaching techniques can be used together.

EVALUATION

EVALUATION OF CBIS

While CBIS can be an effective tool for teaching certain types of concepts and techniques, it has been very difficult to evaluate. Often this difficulty is due partly to a lack of understanding of what the simulation is supposed to be teaching and partly to a lack of good methodology for evaluating a student's performance.

Suppose that a teacher has some material that he thinks can be taught best using CAI. He should only use CBIS if he can demonstrate to himself, at least, that the material falls into one of the three categories described above: process concepts, relationships between concepts, or multifaceted/multi-step problem solving. Otherwise he should opt for some other type of CAI. One major problem with CAI is that authors of material fit the material to the mode of instruction, instead of fitting the mode of instruction to the material. The author should write a series of goals and objectives, and then decide which material would be best taught using CBIS and which using other methods. Defining goals and objectives will also help cut down the amount of development time required. In writing down his goals and objectives, the author has begun the process of writing the evaluation, that is, he has something that he can test for. But, if the author's material is suitable for CBIS, the author faces the problem that there are few methods available for the evaluation.

Evaluation of a CBIS Package: "The Salesman on the Beach"

The evaluation problem was encountered in tests of two CBIS packages written to teach spatial marketing principles to beginning undergraduate, human geography students. The first, called "The Salesman on the Beach" (Rushton, et. al.), was developed in the early 1970s to teach the principles of spatial competition in one spatial dimension. The student is told that there are two ice cream salesmen attempting to sell ice cream on a beach, and both are attempting to maximize their profits. The salesmen can move their ice cream wagons anywhere along the beach — the location is initally the only changeable variable. Two students represent the two ice cream salesmen who must decide where they should locate to make the most profit. Each student is faced with environmental considerations beyond his control — the location of the population that is non-uniform across space and the other student's location. In later units the students also control the price. This material fits the range of CBIS applications because the students are learning process concepts and how to solve multifaceted problems.

This package was among the first interactive CBISs in geography and thus the first version was a bit rough because there were no clear principles or properties of a well written CBIS. A second version was constructed attempting to follow more closely the properties described above. However, the hardware limited the attempt — only 300 baud hardcopy terminals were available at the time, so that while the terminals' and system's capabilites were maximized, these were little more than the standard ASCII teletype-33 capabilities. While the documentation was extensive for the time, a 13 page student manual and a 27 page instructor-programmer's manual, the manuals were somewhat deficient. This deficiency was due primarily to a lack of guidelines. Additionally, the program had no ancillary materials though the lesson units were constructed on a scale of graduated complexity. Thus, at the outset, this package should have been less than completely successful.

An experiment was run in 1973 to test the utility of this package. It was hypothesized that a group of students using the CBIS package would show a problem solving ability superior to that of a group of students using traditional methods, but that the CBIS group's ability to define concepts would be slightly poorer. The results of the experiment (table 1) showed these tendencies, but not to a statistically significant degree (Ellinger and Frankland).

TABLE 1

Student's t Test of Difference Between Control and CAI Groups*

	Total	Definition Section	Problem Solving Section
Pretest	1.45	0.21	0.40
Posttest	0.46	0.33	0.65

*after Ellinger and Frankland

The conclusions were indefinite. First, either instructional method worked equally well. Second, the costs were definitely all in favor of the traditional methodology; it was recognized that the costs of all CAI would continue to decline so that cost would not be a factor (or would favor the CBIS material). Third, many of the students using the CBIS material felt they learned more and that the material was presented in a more enjoyable fashion than by learning the same material in the traditional manner. But the CBIS program still had some problems — the chief being the length of time the student had to wait while the program was printing out (this was more a function of the terminal speed than of any inherent programming problem).

Evaluation of the "Spatial Marketing Simulation"

A second experiment has just been completed on another geographic CBIS package. This package, "Spatial Marketing Simulation," was developed in 1976-77 to teach descriptive spatial location theory to beginning economic and human geography students. The theory deals with how firms choose to locate within a region (the size of a state) and why firms that chose certain locations within the region were successful or unsuccessful. This theory is much more complex than the model previously described, requiring a student to deal with many more economic process concepts and the relation-

ship between these concepts when they interact with the dependent variable. The theory is designed to teach the ability to solve the problems of "where a firm should locate to make the greatest profit or the least loss" and "why some firms are successful and some unsuccessful." This theory is an obvious candidate for a CBIS package, following the ideas suggested above.

The package fully develops the properties described above, making full use of a semi-graphics terminal with cursor addressing; page, line, and element erasure; and many other terminal functions, as well as many software functions, like disabling and sensing break. The package is well documented with a 17 page student manual, a 55 page instructor-programmer's guide, and a 15 page user's guide, plus a large number of interactive help units designed to give help at any query in the simulation part of the package. There are seven lessons, taking approximately 12 hours to complete, designed to teach the students the concepts, relationships, and necessary problem-solving skills to properly use the simulation. This package has all of the necessary properties described above of a good CBIS package.

In the experiment, one section of beginning human geography students received instruction via the CBIS package, while two sections received instruction via the traditional lecture/discussion/paper and pencil exercises (Ellinger and Brown). A pretest revealed no significant differences between the groups. The results of the posttest are shown in table 2.

TABLE 2

Evaluation of the Spatial Marketing Simulation

	Total test		Definitions		Relationships		Problem Solving	
	CBIS*	Control+	CBIS	Control	CBIS	Control	CBIS	Control
Mean	11.76	8.19	2.96	2.84	5.18	3.89	3.75	2.07
S.D.	2.98	2.66	1.05	.97	1.44	1.44	1.58	1.57
t-value	3.68		.406		2.84		3.41	
Prob.	<.0001		n.s.d.		<.005		<.001	

The mean, S. D., t, and probabilty values are given for the total posttest scores and for three subscores of interest.

Although significant differences favoring the CBIS group were found on the posttest total score, the subscore results are more interesting. For the "definition" subscore results, the group differences are not significant, with the CBIS group mean slightly higher. The absence of significant differences in performance for simple factual recall was expected because this is a known capability of the traditional method and is not an exceptional capability of CBIS. Results similar to these are frequently observed in comparisons of instructional simulations with "traditional" instruction.

Without the two additional subscores, which along with the definition subscore constitute the total score, we would not have observed any superior performance attributable to the CBIS group. On the subscores reflecting CBIS's capability to teach the ability to solve multifaceted/multi-step problems and the ability to properly relate two or more process concepts, the differences observed between the groups were as predicted.

The contrast in the student performance outcomes of the two experiments above is so marked as to require no further comment. However, some comments on other differences may be worth noting. First, clearly stated instructional objectives were presented for the design, implementation, and evaluation of the "Spatial Marketing Simulation," while derived objectives were stated at the time of revision for "The Salesman on the Beach." Second, the careful development of an evaluation instrument (also based on the instructional objectives), that allowed observation of three types of performance, permitted the observation of group differences. The relative lack of precision of the posttest for "The Salesman on the Beach" simulation did not permit the observation of differences in performance. At this time it is impossible to say whether any unassessed differences between the groups existed.

CONCLUSION

While they are not new or original, we feel that the "whens and hows" discussed here have served us well; we recommend them to you. First, make sure that the material and instructional design requires CBIS; second, use of full capabilities of the terminal and computer system; third, document; fourth, use ancillary material to the fullest extent when needed. In your formative evaluation, test for those process concepts, relationships, and problem-solving abilities that you have developed the simulation to teach. For the accomplishment of appropriate instructional tasks, a well designed CBIS package is a powerful teaching tool. Such a CBIS package when properly evaluated should show clear cut, observable, instructional benefits.

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